Matchmove

CS4340 Digital Special Effects

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Introduction

What is matchmoving?

- Purpose: To place CG elements in live-action footage as though they are in the real scene.
- Relatively easy if camera in live-action footage is stationary.
- Otherwise, need to match camera motion.
  - Recover camera parameters: calibration.
  - Recover camera motion path: tracking.
  - Reconstruct spatial layout of 3D environment: 3D reconstruction.
- Camera parameters, motion path, 3D coordinate systems are imported to animation software, e.g., Maya.

To understand matchmoving, need to understand:

- camera
- calibration
- tracking

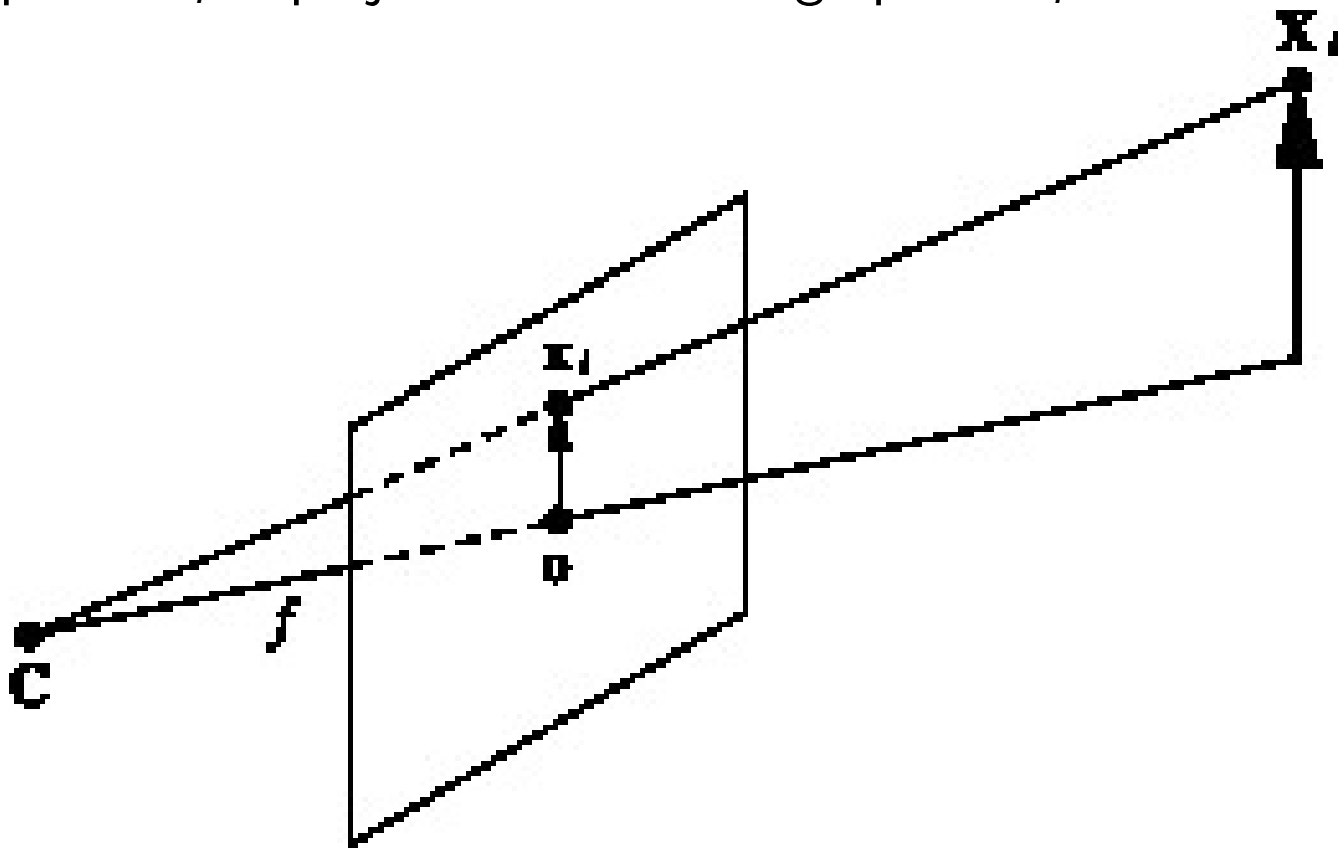
Here, we present basic ideas.
For details about algorithms, refer to

CS4243 Computer Vision and Pattern Recognition

Camera

Perspective Camera Model

3D object point $\mathbf{X}_i$ is projected to 2D image point $\mathbf{x}_i$.



- **C**: camera center, f: focal length, **o**: principal point.

In mathematics, with stationary $\mathbf{X}_i$,

$$\mathbf{x}_i(t) = \mathbf{K}[\mathbf{R}(t)\mathbf{X}_i - \mathbf{R}(t)\mathbf{C}(t)] \tag{1}$$

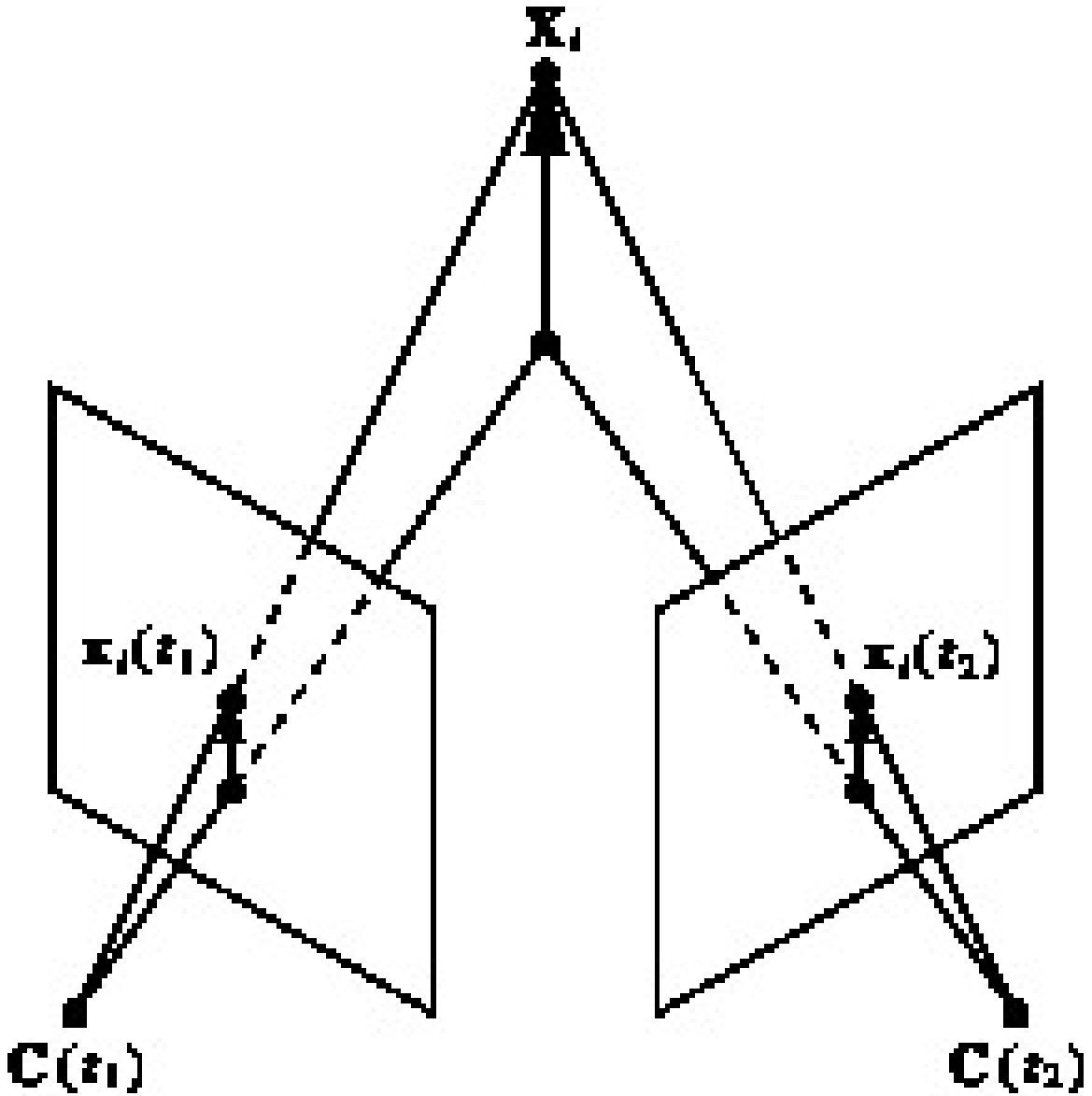
where

- $\mathbf{R}(t)$ is camera's orientation in world coordinate frame at time t.
- $\mathbf{C}(t)$ is camera center in world coordinate frame at time t.
- $\mathbf{K}$ is camera matrix, contains camera parameters:

$$\mathbf{K} = \begin{bmatrix} \alpha f & s & o_x \\ 0 & f & o_y \\ 0 & 0 & 1 \end{bmatrix} \tag{2}$$

- α: aspect ratio, f: focal length, s: skew, $\mathbf{o}$: principal point

When camera moves, 3D point projects to different 2D image points.



In addition, there is lens distortion.

(a) No distortion.

(b) With lens distortion.

2th-order Radial distortion:

$$\mathbf{x}'_i = (1 + \kappa r_i^2)\,\mathbf{x}_i \tag{3}$$

where

- $\mathbf{x}'_i$ is distorted coordinate
- κ is distortion coefficient
- $r_i^2 = x_i^2 + y_i^2$

- To be more accurate, use higher-order distortion model.
- Can also include tangential distortion model.
- Will discuss about algorithm in Image Morphing lecture.

Recap:

$$\mathbf{x}_i(t) = \mathbf{K}[\mathbf{R}(t)\mathbf{X}_i - \mathbf{R}(t)\mathbf{C}(t)] \tag{4}$$

- If corresponding $\mathbf{X}_i$ and $\mathbf{x}_i(t)$ are known, can solve for $\mathbf{K}$, $\mathbf{R}(t)$, $\mathbf{C}(t)$.
- But, in matchmoving, $\mathbf{X}_i$ are unknown!
- Fortunately, can still compute $\mathbf{K}$, $\mathbf{R}(t)$, $\mathbf{C}(t)$ if we know $\mathbf{x}_i(t)$ at different time t, i.e., in different image frames.

Main Ideas:

- Determine $\mathbf{x}_i(t)$ from input images: 2D point tracking.
- Use tracked $\mathbf{x}_i(t)$ to solve for $\mathbf{K}$, $\mathbf{R}(t)$, $\mathbf{C}(t)$: camera calibration and tracking.
- Finally, can compute $\mathbf{X}_i$: 3D reconstruction.
- MatchMover Pro can perform all these.

Matchmoving in MatchMover

Steps in Matchmoving

1. Import live footage into MatchMover.
2. Track 2D points in live footage.
3. Calibrate and track camera.
4. Create 3D coordinate frame.
5. Export camera parameters and motion path to 3D animation software, e.g., Maya.

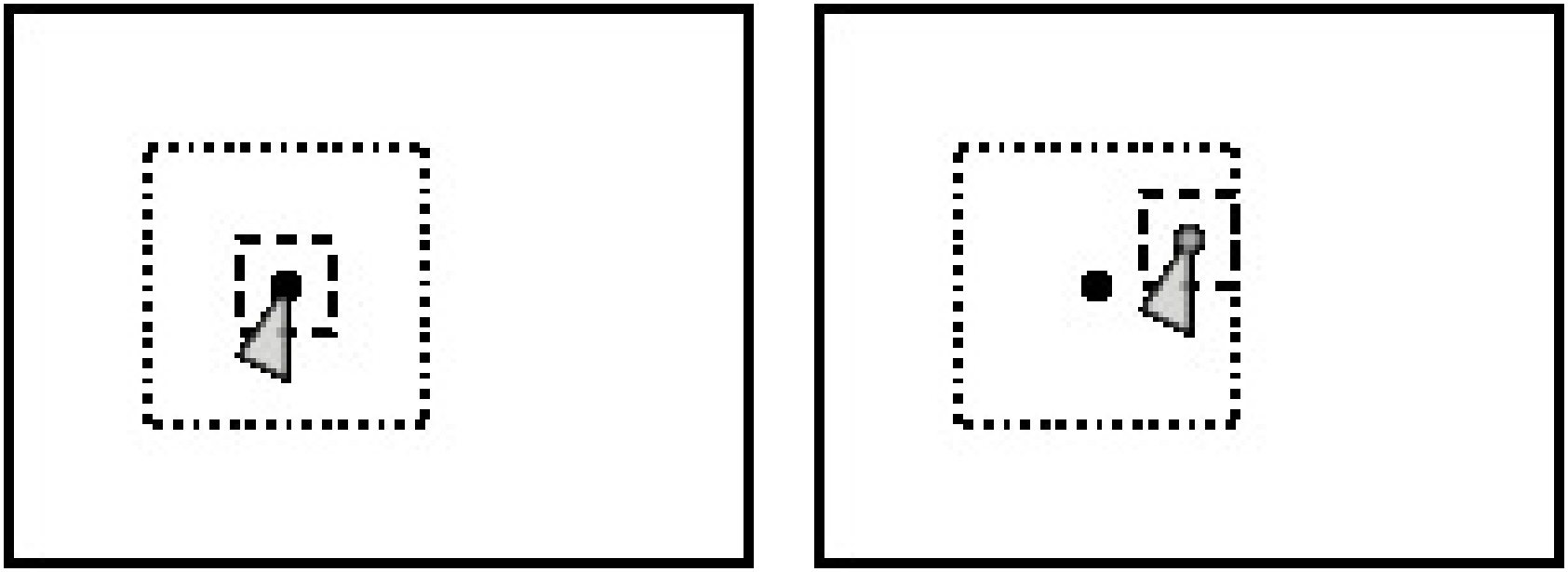
See [1, 3] for details and tutorials.

Tracking 2D Points

MatchMover uses feature-based tracking algorithm.

- Look for distinct features or patterns to track.
- Example: corners.

Feature-Based Tracking



(a) image at time t (b) image at time $t+1$

1. Look for distinct features enclosed in pattern zone (dashed box).
2. For each feature,
   - Search for feature within search zone (dotted box) in next frame.
   - Find best matching location in search zone.
3. Repeat for all features in image.

MatchMover's tracking algorithm is quite sophisticated.

- Can set the size of pattern zone and search zone.
- Can use gray level (faster) or color (slower but more accurate).
- Can predict positions of tracked points.
- With subpixel accuracy, i.e., fractional pixel position.
- Measure tracking quality.
- Can specify starting and ending frames of a track.

MatchMover supports two tracking modes:

1. Automatic Tracking
   - Track many points at the same time.
   - Use 3D coherency in tracking.
   - Select best automatic tracks for camera calibration and tracking.
   - Perform camera calibration and tracking automatically.
2. Supervised Tracking
   - User selects the points to track.
   - Track one point at a time.
   - Cannot use 3D coherency.
   - Does not perform camera calibration and tracking automatically.

These two modes can be used in combination.

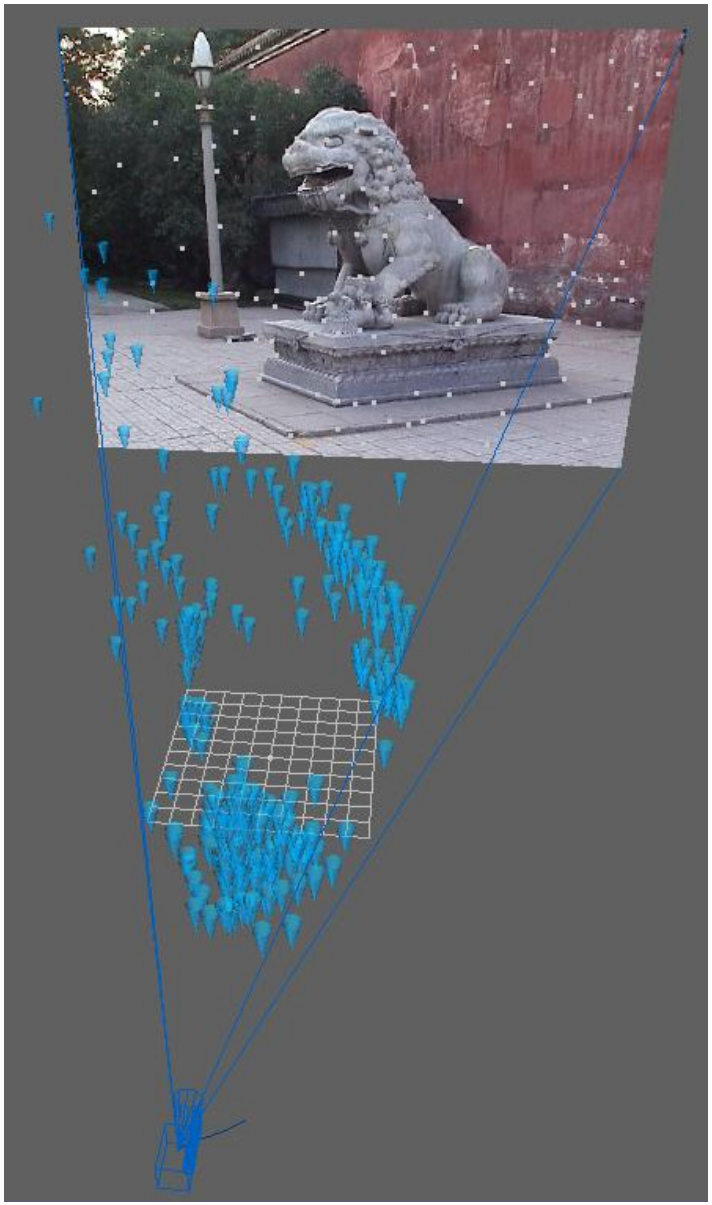
Example: Automatic 2D tracking results.

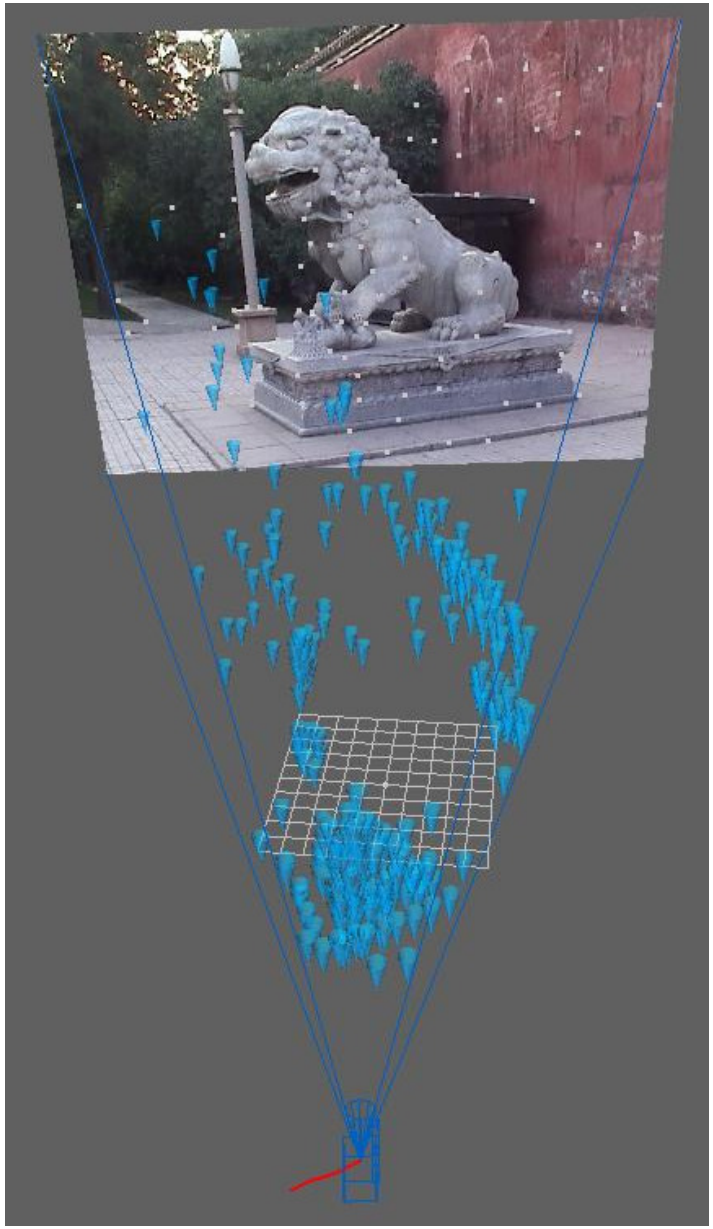
Tracking quality: green = good, yellow = fair, red = poor.

Reconstructed 3D points: Camera's view.

Demo: lion-3D.avi

Reconstructed 3D points: 3D views.



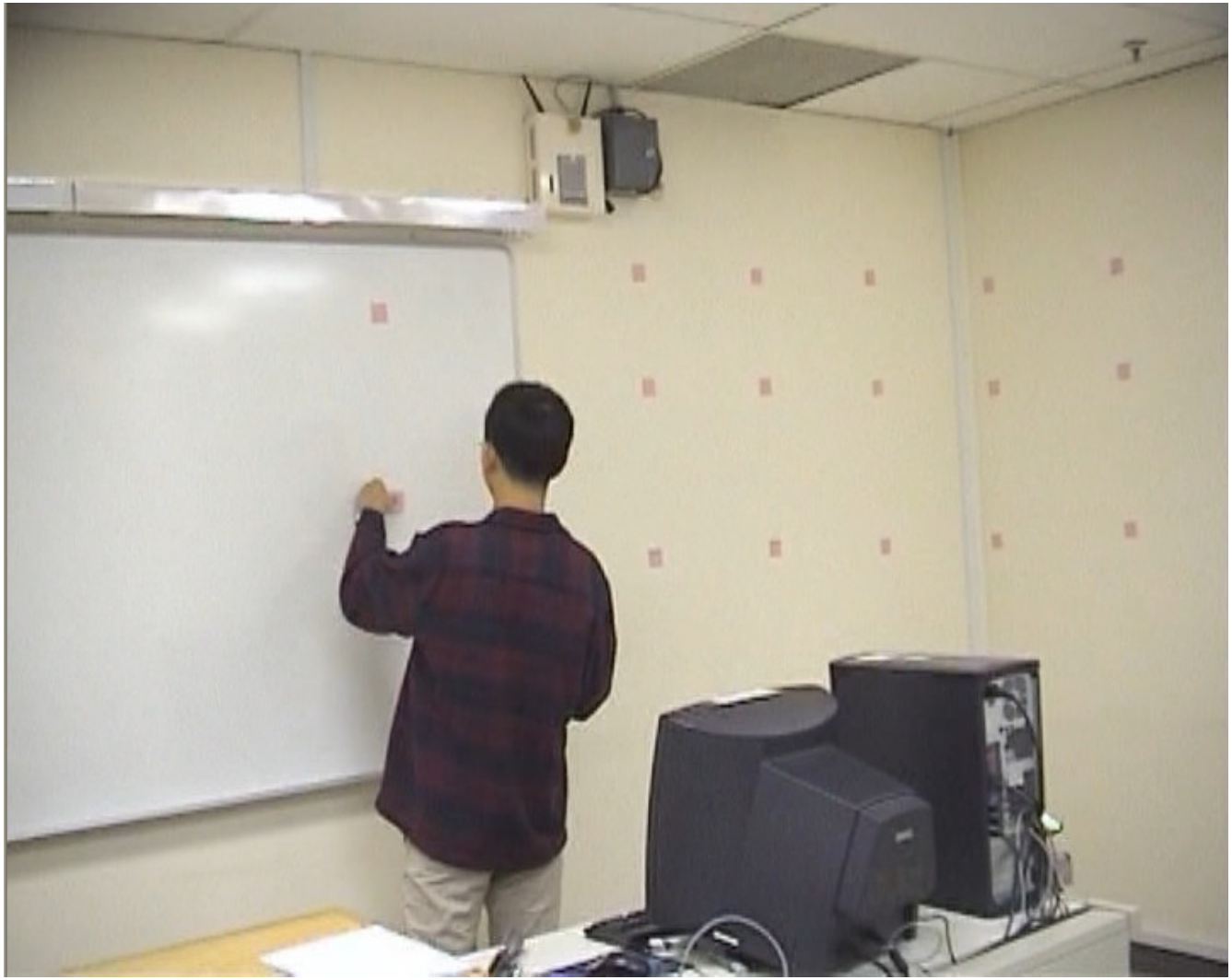


Tracking Tips

- Track distinct points such as corners.
- Track points on stationary objects.
- Track true 3D points instead of boundaries between objects.
- Cover 3D space with adequate number of track points.
- Track enough points for accuracy and robustness in camera calibration.
- Tracking results don't have to be perfect.
  Just need to be good enough for good matchmoving.

If scene is too homogeneous, create features for tracking.

Example: *Magic Glove* (2005).



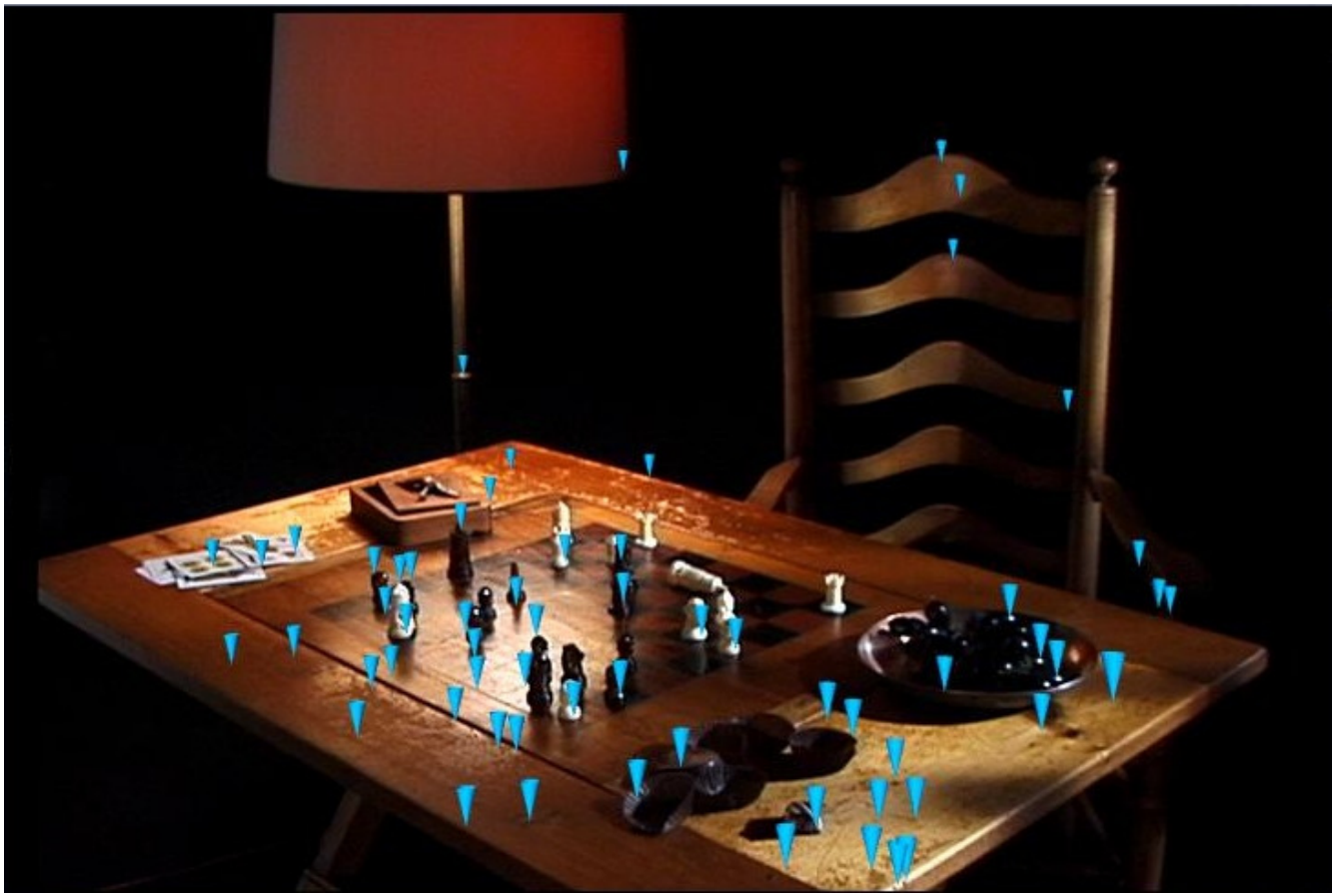
Demo: Magic Glove - makingof.mpg

Matchmove Examples

Automatic 2D tracking results with track cleaning:

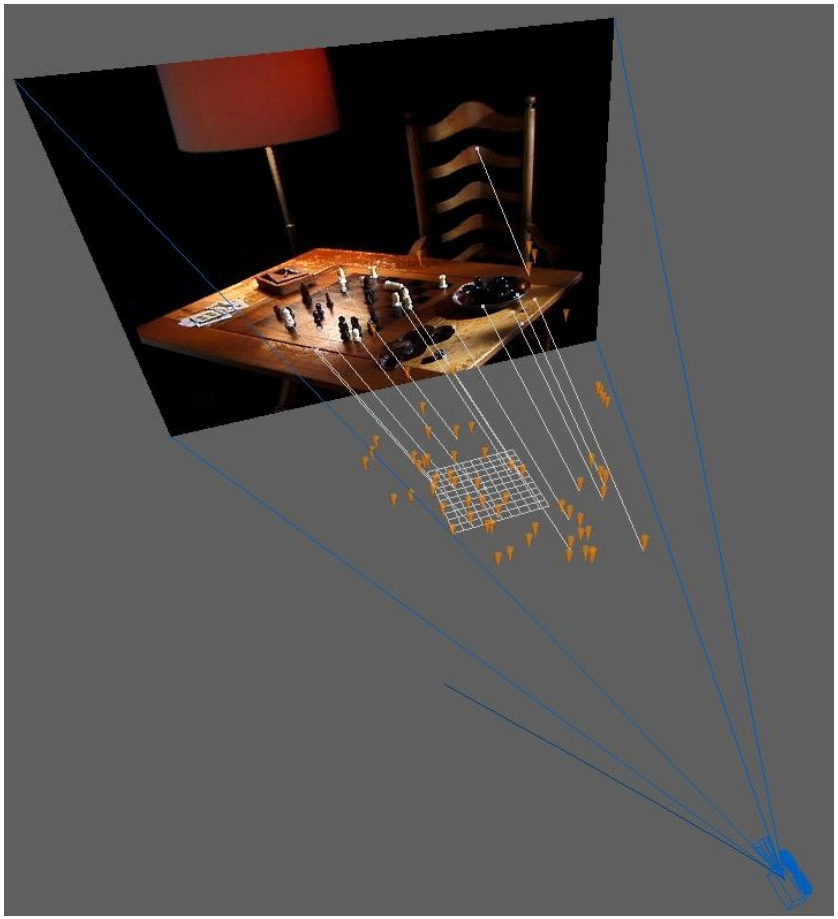
- Average 30 best tracks per frame.
- Each track lasts at least 10 frames.

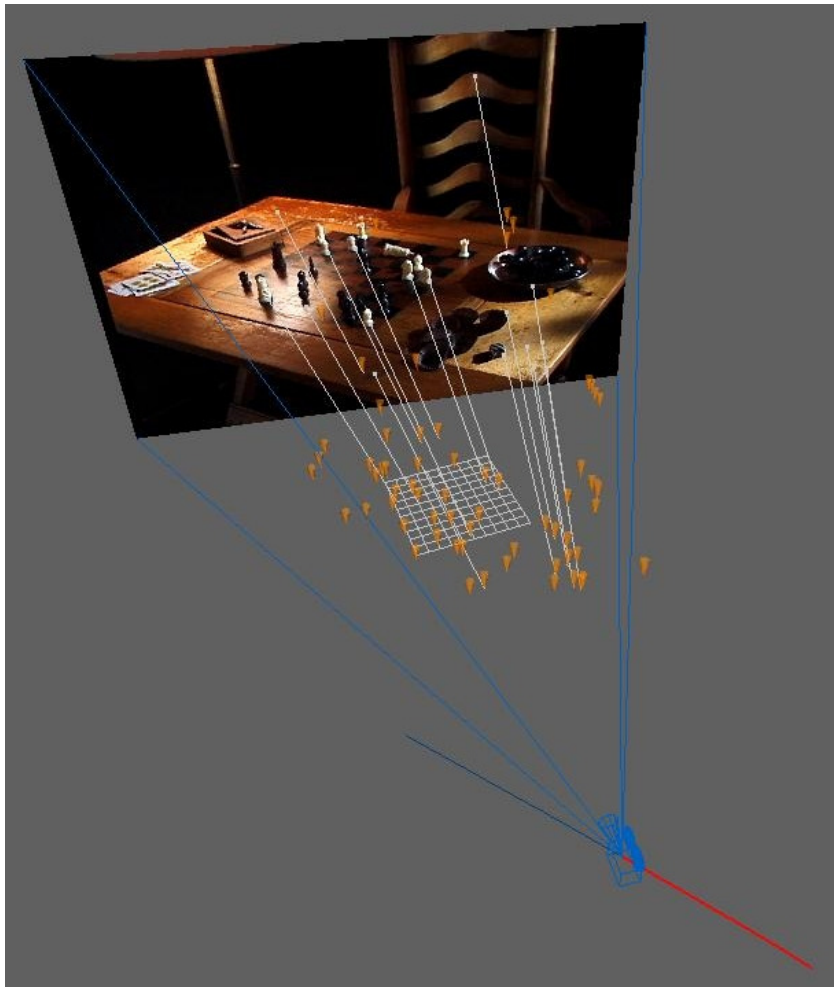
Reconstructed 3D points: Camera's view.



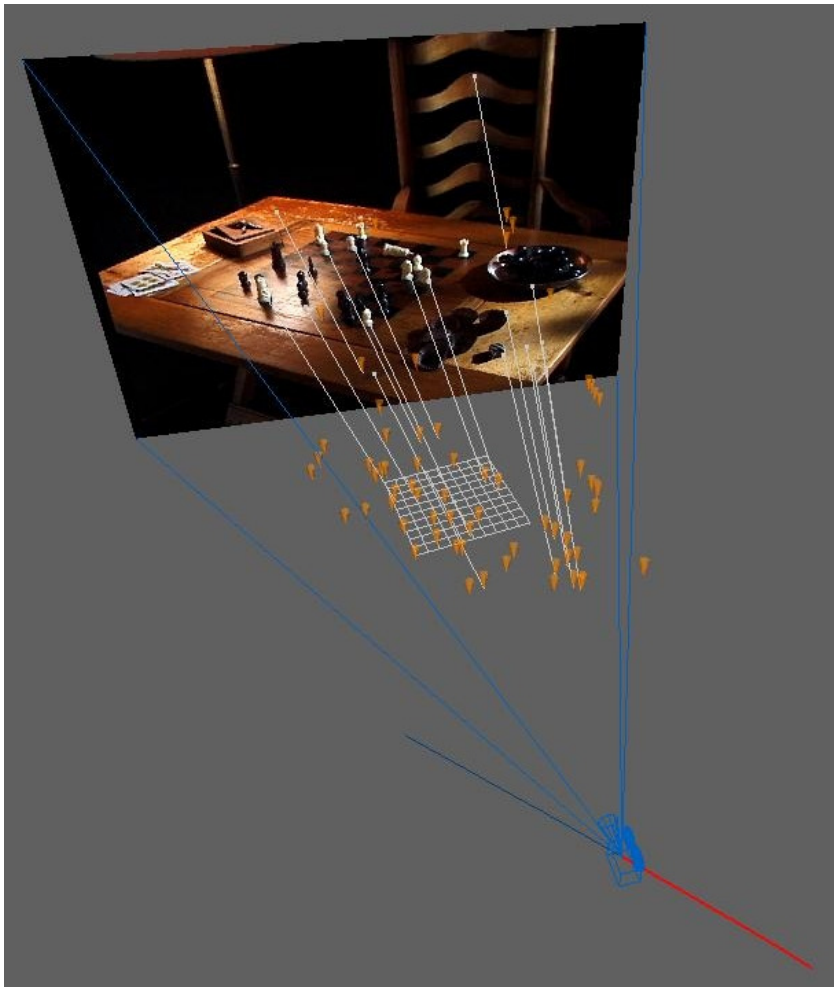
Demo: chess-3D.avi

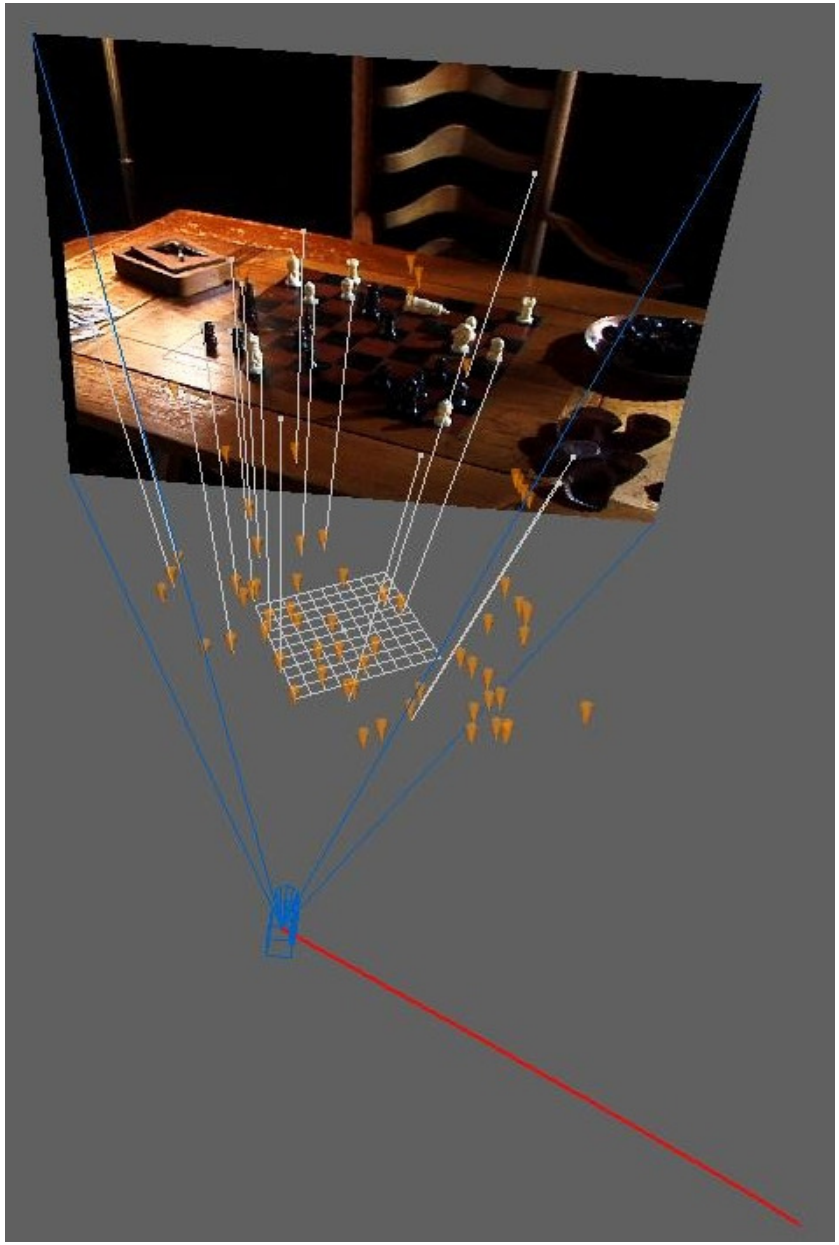
Reconstructed 3D points: 3D views.





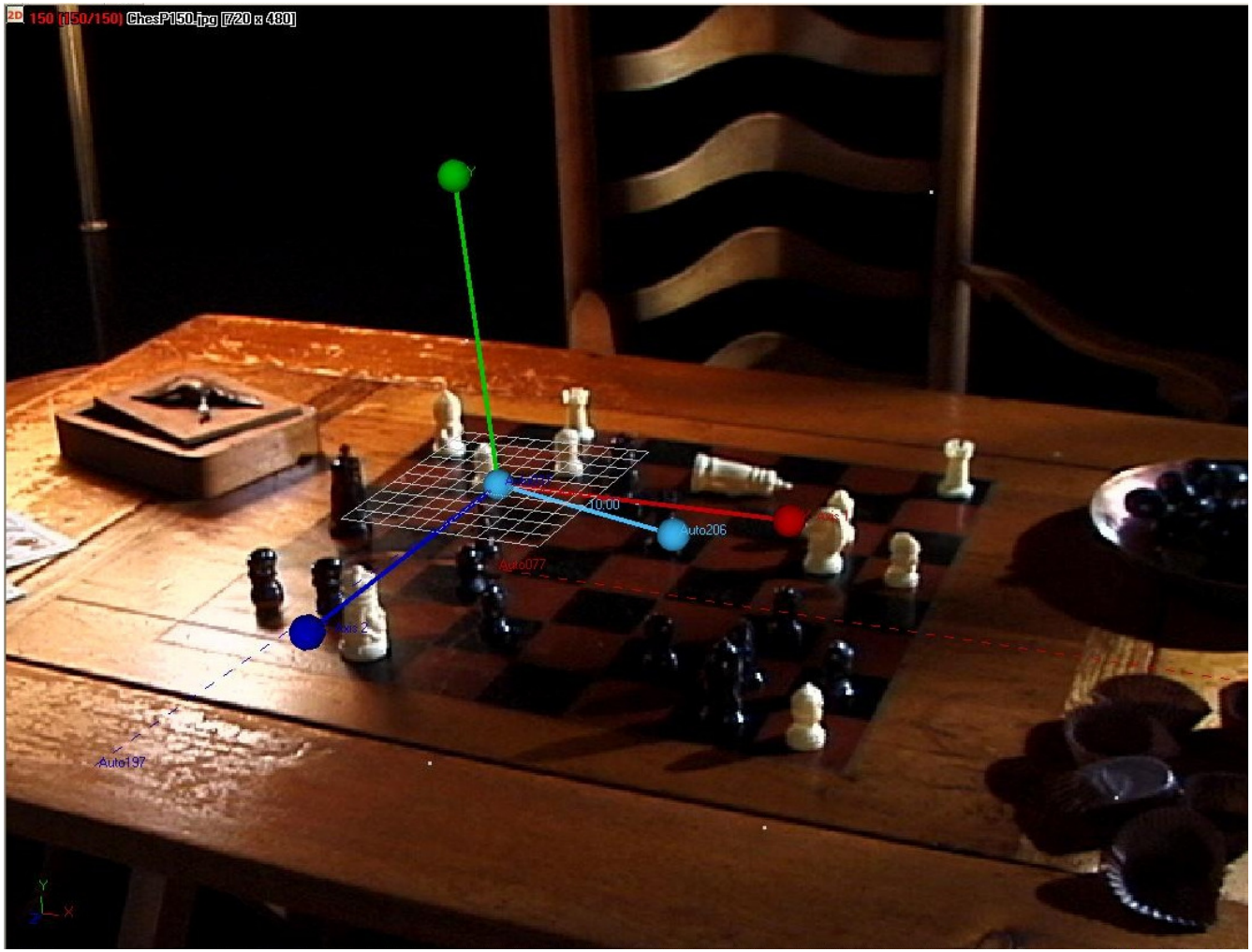
Reconstructed 3D points: 3D views.





Create 3D coordinate frame:

- X-Z plane should be aligned with horizontal object, e.g., table.



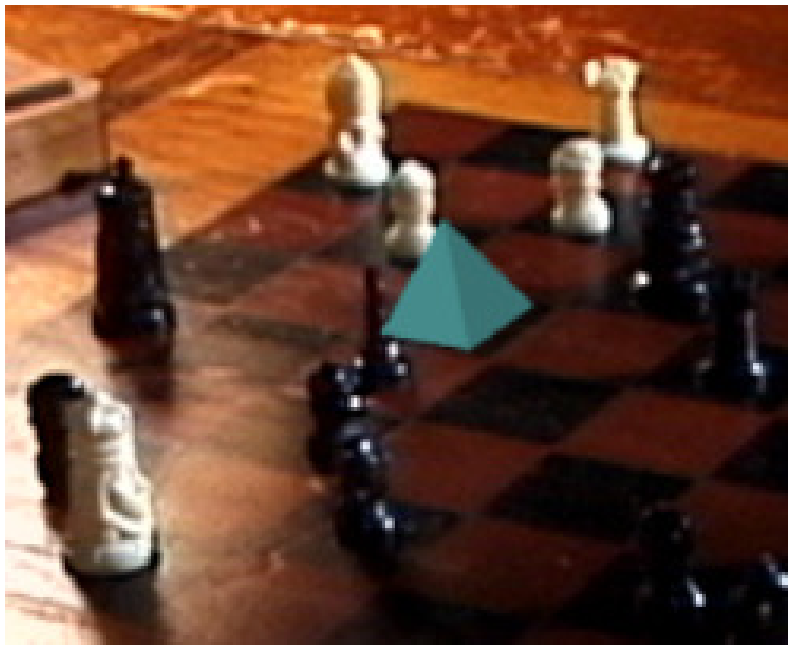
Insert 3D CG object:

- CG object should appear stationary while camera moves.

Demo: chess-good.avi

Be careful!

- CG object should occlude the real object behind it.
- But, it should not occlude the real object in front of it.
  Why does this problem happen? (chess-bad.avi)



More matchmove example

- The Lord of The Rings [2]

Further Readings

- [1]: Matchmoving reference book.
- [3]: REALVIZ MatchMover Pro User Guide.
- [4]: More matchmoving examples.

References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Matchmoving: The Invisible Art of Camera Tracking.
Sybex, 2005.


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MatchMover Professional 3.0 User Guide.
Realviz S.A., 2004.


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sfx.realviz.com/gallery/list.php?product=mpro.